Neutron Detection Efficiency in the SNO Detector

A. D. Marino[1], C. A. Currat[1], Y.D. Chan[1] , K.T. Lesko[1], E.B. Norman[1], A.W. Poon[1], R.G. Stokstad[1] for the SNO Collaboration
[1]*Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720*

The Sudbury Neutrino Observatory was designed to determine the total flux of solar neutrinos via the following reaction on deuterium:

$$\nu + d \rightarrow \nu + p + n, \tag{1}$$

which results in the production of a free neutron. When a free neutron is produced in SNO, by the NC interaction or another means, it will rapidly thermalize and then walk randomly around the detector before capturing and producing an observable signal. To determine the flux of solar neutrinos via the neutral-current interaction, we must understand the total neutron capture efficiency integrated of the entire volume of interest.

The primary source used in SNO for the calibration of the neutron capture efficiency a ^{252}Cf source. However, this dissertation will present an alternate calibration technique using an Americium-Berylium (AmBe) source, which has the advantage of being a tagged neutron source. In this source, ^{241}Am emits α-rays which strike a ^{9}Be target, producing neutrons via the ^{9}Be(α,n)^{12}C reaction, which has a Q-value of 5.7 MeV. Figure 1 depicts the populated levels in ^{12}C. The 4438 KeV state will always emit a γ-ray. The exact ratio of 4.439 MeV γ-rays to neutrons depends on the initial spectrum of the αs. For the αs from ^{241}Am, it has been measured that 59.1±1.5 percent of the reactions yield a 4.439 MeV γ-ray [1] . Since the neutrons will take ∼ 5 msec to thermalize and capture in the salted D_2O, the gamma will be detected before the neutron. The decay rate of the source is a few Hz.

We can express the number of observed coincidences as

$$N_{coinc} = N_{neutron} \times \frac{N_\gamma}{N_{neutron}} \times \varepsilon_n \times \varepsilon_\gamma, \tag{2}$$

where ε_n is the efficiency for detecting neutrons, ε_γ is the efficiency for detecting the 4.4 MeV γ-rays, N_γ is the number of γ-rays emitted by the source, and $N_{neutron}$ is the number of neutrons emitted by the source. This can be rearranged as

$$\varepsilon_n = \frac{N_{coinc}}{N_\gamma \times \varepsilon_\gamma}. \tag{3}$$

Here the numerator is the number of observed coincidences and the denominator is the number of observed γ-rays. So, this gives us a method of determining the neutron capture efficiency for a given source run.

To determine the number of observed γ-rays in a given source run, we can perform a fit to the energy distribution for the events. To determine the number of coincidences, we can study the distribution of time to the next event. In principle, we expect to see a 5 msec exponential corresponding to the time between a gamma and it associated neutron for the neutron gamma coincidence. When there is no coinicidence, we would expect that the time to the next event should follow an

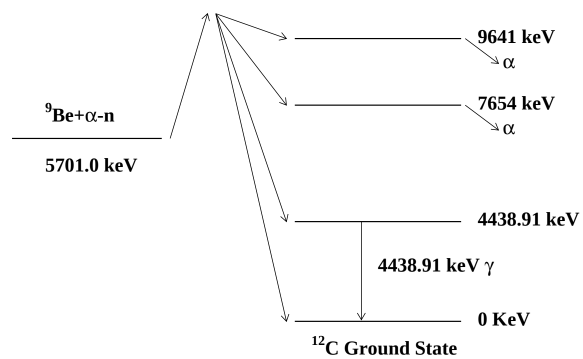

FIG. 1: This drawing, based on one in [1], depicts the levels involved in the ^{9}Be+α-n reaction.

exponential with a slope of a few Hz, corresponding to the time between subsequent AmBe source interactions. So, be performing a fit to the time to next event distribution for an exponential plus the background, we can extract the number of observed coincidences.

The source has been deployed at a number of radial locations. Looking at the efficiency a function of the source position, it is possible to determine the integrated neutron detection efficiency within the fiducial volume and above the energy threshold. A preliminary result for the the neutron detection efficiency of $39.1\pm^{1.6}_{2.0}$ % has been obtained for the second phase of SNO with NaCl added into the D_2O. The result is consistent with the result obtained with the ^{252}Cf source, and it represents a factor of three increase in the neutron detection efficiency compared to the first pure D_2O phase of SNO.

[1] S. Croft, Nucl. Inst. Meth. A **281**, 103 (1989).